

Chapter 2 – Design Considerations

2.0 General

2.0.1 Scope

Greenhouse structures designed per this manual shall meet the requirements of the International Building Code (IBC), referred also as the code. The IBC adopts portions of ASCE 7 by reference, which must be included as design loads.

This manual provides commentary on the load requirements of the IBC and ASCE 7 as it applies to greenhouses, load and design requirements for the design of greenhouse structures, their components and enclosure elements (cladding). The loads specified herein are based on the ASCE 7. The loads are to be used in conjunction with the stress criteria of the International Building Code and referenced standards. Where no standards are referenced in the building code, recognized manufacturer's literature may be used with regard to code compliance.

2.0.2 Definitions

- Loads:
 - Dead and Live Loads - defined by the building code
 - Environmental Loads - defined by the building code
 - Collateral Loads - weight of support equipment used for the operation or maintenance of plant material, including water
 - Plant Live Load - weight of supported or suspended plant material
- Importance Factors: I_w (wind), I_s (snow), and I_p (seismic) - a factor that accounts for the degree of hazard to human life and damage to property

2.0.3 Limitations

The scope of this manual is intended for greenhouse structures. The design of special structures must refer to the code for conditions that are applicable.

2.1 Basic Requirements

2.1.1 Design

Greenhouse structures and all parts thereof shall be designed and constructed to safely support all loads specified in this manual and the building code. These loads include the dead and live, collateral loads, environmental loads and equipment loads specified by the purchaser.

2.1.2 Serviceability

Greenhouse structures and their components shall have adequate stiffness to limit vertical and transverse deflections, vibrations or any other deformation that may adversely affect their serviceability.

Dead and live load deflection shall not exceed the deflection limits specified in the building code. Table 1604.3 of the IBC gives vertical deflection limits as $l/120$. While there are drift limits in the code for seismic design (IBC, Section 1617.3), lateral displacements are not regulated by the code for wind.

However, even when wind loads govern the design of a building, the lateral-force-resisting systems shall meet seismic detailing requirements and limitations prescribed in the code. See Section 2.6.5 of this Manual.

Cladding attachment must be designed to accept differential movement under loads.

2.1.3 Analysis

The design of greenhouse structures, the load effect on the individual components and connections shall be by rational engineering analysis methods. Rational engineering analysis is a computational analysis, either by hand or computer, that uses accepted load distribution and determination methods. Unusual structural and construction methods shall be based on engineering analysis or physical testing by an approved laboratory.

Greenhouse structures shall be analyzed for all building code required load conditions. Elements and components shall be designed for load combinations specified in the building code or referenced standards.

2.2 Administrative Issues

2.2.1 Design Requirements

Prior to design the manufacturer should obtain local load information, i.e. wind, snow, etc. Information should include:

Code of jurisdiction

Determination of loads:

- Roof Live Load
- Wind speed (3-second gust wind speeds)
- Snow load (ground snow load)
- Earthquake zone or design spectra

Soil type and allowable pressure

2.2.2 Required Information on Plans

Certain information must be shown on the construction drawings. The following information shown below is required even if it is not a controlling design load. Information to be provided on the plans includes:

- Dead Loads
- Roof Live Loads
- Collateral Loads (irrigation equipment, including water)
- Plant loads
- Snow Loads
 - Ground Snow Load p_g
 - Flat-roof snow load, p_f
 - Snow exposure factor, C_e
 - Snow load importance factor, I_s
 - Thermal factor, C_t
- Wind Load
 - Basic wind speed (3 second gust), miles per hour
 - Wind importance factor, I_w and building category
 - Wind exposure category
 - Applicable internal pressure coefficient and prevailing wind direction
 - Design Wind Pressure on Components and cladding.
 - Exterior components and cladding materials are not specifically designed by the Design Professional.
- Earthquake design data
 - Seismic use group
 - Spectral response coefficients (S_{DS} and S_{D1})
 - Site class
 - Basis seismic-force resisting system
 - Design base shear
 - Analysis procedure
- Flood load - If a building is located in a flood hazard area, established by a jurisdiction having authority, the following shall be shown for areas not subject to high-velocity wave action:

Elevation of the lowest floor

Elevation to which any nonresidential building will be dry floodproofed

- Foundation Design

Reactions of structural elements when the foundation or other systems are to be designed by others. If the structure is designed for future additions, the foundation information should include the probable design load information.

2.2.3 Additions and alterations

Additions to existing greenhouses may be made. The new structure shall not make the existing structure unsafe. The definition of unsafe and dangerous is included in the code or supporting documents. For structural purposes it is related to the percent of overstress in structural members.

When a greenhouse is added to an existing building, the capability of the building to withstand any loads superimposed by the greenhouse shall be verified including lateral loads due to attachment and snow drift loads due to proximity.

Alterations may be made to any greenhouse if the new work complies with current code provisions and any loads imposed on the existing structure do not create an unsafe condition.

2.2.4 Load Testing

Load testing is an option provided for in the code. Load testing is typically not desirable for any product that is within the scope of computational analysis. Typically, specialty products such as cladding components are candidates for testing rather than calculations. Any load testing must be carried out by an independent approved testing agency.

2.3 Design Methodology

2.3.1 Allowable stress design vs. strength design requirements - Design of typical greenhouse structures may be made by using the allowable stress design (ASD) or the strength (LRFD) design methods. The load combination equations used will depend on the design method. The ASD is the most common approach used by most engineers for greenhouse structures.

2.3.2 Safety factors for greenhouse components - Safety factors for the structural members are included in the code referenced standards.

2.3.3 Greenhouse classification (Code occupancy group under IBC 2000) - Greenhouse structures may be considered an occupancy classification "U" when used as a Production Greenhouse. Research facilities may be considered the same .

Commercial greenhouse structures used for retail use are considered as a "B" or "M" occupancy classification. This is based on the fact that the building is normally occupied.

2.3.4 Deflection and Drift - Deflection of greenhouse components are defined in IBC - Table 1604.3. *There is no criteria limiting drift. The engineer should consider the serviceability requirements of the building, previously discussed in Section 2.1.2 of this manual.*

2.4 Loads

2.4.1 General

Buildings and other structures shall be designed to resist the load combinations specified in the Chapter 16 and Chapters 18 through 23 of the IBC. Applicable loads shall be considered, including both earthquake and wind, in accordance with the specified load combinations. Effects from one or more transient loads not acting shall be investigated.

2.4.2 Dead loads

- Structure weight
- Cladding weight

2.4.3 Live loads

2.4.3.1 Roof

- 10 psf minimum in the IBC (ASCE-7 permits the Authority having jurisdiction to accept 10 psf.)

2.4.4 Collateral Loads

Collateral loads shall not be included in Wind Uplift resistance analysis. These loads shall be considered a live load for wind design.

- Mechanical Equipment - Irrigation, transfer systems, etc.
- Permanently mounted service equipment (heaters, fans, water lines, etc.) Such permanently mounted equipment shall be considered dead load when considering load combinations.

2.4.5 Plant Loads

- Hanging plants, 2 psf minimum , applied as a concentrated load at the truss panel points. *Greenhouse purchasers may have additional or other criteria for hanging plant loads or mechanical watering systems.*

2.5 Snow

2.5.1 General

Provisions for the determination of design snow loads on greenhouse structures are per ASCE 7-98 (Section 7.0). They apply to the calculation of snow loads for both continuously heated greenhouses and for intermittently heated or unheated greenhouses.

2.5.2 Definitions

The following definitions apply only to this section.

Continuously heated greenhouse. Any greenhouse, production or commercial, with a constantly maintained interior temperature of 50°F or more during winter months. Such a greenhouse must also have a maintenance attendant on duty at all times or a temperature alarm system to provide warning in the event of a heating system failure. In addition, the greenhouse roof material must have a thermal resistance (R-value) less than 2.0 ft²·hr·°f/Btu.

Intermittently heated or unheated greenhouse. Any greenhouse that does not meet the definition of a continuously heated greenhouse.

2.5.3 Design Procedure

The elements outlined herein are the general process for snow design. Individual building configuration may dictate additional design requirements as specified in the code.

Design snow loads for greenhouses shall consider:

- The ground snow load p_g - based on map in code or local requirements
- The flat-roof snow load p_f calculated taking into consideration the roof exposure, the roof thermal condition, and the occupancy of the structure.
- The sloped-roof snow load p_s for greenhouses with gabled, hipped, arched, and gutter-connected roofs shall be determined as referenced in 2.5.4 of this manual.
- Partial loading conditions to account for wind scour, melting, or snow-removal operations shall be considered as referenced in 2.5.4 of this manual.
- Unbalanced snow loads due to the effects of winds on sloped roofs shall be considered as referenced in 2.5.4 of this manual.
- Local snow load surcharges due to snow drifts on lower roofs and from roof projections as referenced in 2.5.4 of this manual.
- Local snow load surcharges from snow sliding off of adjacent higher sloped roofs shall be considered as referenced in 2.5.4 of this manual.

2.5.4 Calculation of Snow Loads

2.5.4.1 Ground Snow Loads: Per ASCE 7 Section 7.0, or local code requirements.

2.5.4.2 Flat-Roof Snow Loads: (ASCE 7, Equation 7-1) Although greenhouses rarely, if ever, have flat roofs, the calculation of flat-roof snow loads, p_f , is necessary for the calculation of sloped-roof snow loads, p_s .

A flat roof is a roof with a slope less than or equal to 5 degrees. For low-sloped roofs, refer to ASCE 7, Section 7.3.4 for further information and load limitations.

First the flat roof snow load p_f is calculated. If the building has a low-slope roof (generally between 5 and 15 degrees), the flat roof snow load will have a minimum value determined by the

Code. The governing flat roof snow load, either calculated or Code-determined minimum, is then used to determine the sloped roof snow load, p_s , by multiplying with a slope factor C_s .

If the building has a sloped roof (greater than 15 degrees), the calculated value for p_f is used, with a slope factor C_s , to determine the sloped roof snow load p_s . For greenhouses, where the ground snow load, p_g , is in the 15 psf to 20 psf range, the snow load will generally govern over the roof live load.

For gutter-connected greenhouses resulting in a multiple folded plate, sawtooth or barrel vault roof, the value of C_s is 1.0.

The flat roof snow load p_f shall be calculated using the following equation, with exposure factor C_e , thermal factor C_t , and snow importance factor I_s found in ASCE 7.

$$p_f = 0.7 C_e C_t I_s p_g$$

The flat roof snow load p_f , for low-sloped roofs only, shall not be less than the following:

$$p_f = I_s p_g, \text{ when } p_g \text{ is less than or equal to 20 psf or}$$

$$p_f = I_s 20 \text{ psf, when } p_g \text{ is greater than 20 psf}$$

Where:

P_g = Ground snow load, per ASCE 7, Figure 7-1

C_e = Exposure factor, per ASCE 7, Table 7-2

C_t = Thermal factor, per ASCE 7, Table 7-3

I_s = Importance factor for snow loading, per ASCE 7, Table 7-4

Exposure Factor: is a function of the greenhouse site terrain category and roof exposure category.

Most greenhouse roofs are likely to be fully or partially exposed and located in Exposures B or C. Thus, the snow exposure factor is most likely to be 0.9 or 1.0.

Thermal Factor: is a function of the thermal resistance of the greenhouse roof glazing and the temperature conditions within the greenhouse, and shall be determined from the following Table:

Table 2.1 - Thermal Factor, C_t

THERMAL CONDITION	C_t
Continuously heated greenhouse (see 2.5.2)	0.85
Intermittently heated greenhouse kept just above freezing	1.1
Unheated greenhouse	1.2
All greenhouses except those above	1.0

Note:

The thermal condition should be representative of the anticipated conditions during winters for the life of the greenhouse.

Snow Load Importance Factor: The value of the snow load importance factor, I_s , used in the calculation of p_f is a function of the type of greenhouse and its use, and shall be determined in accordance with the following Table:

Table 2.2 - Classification of Greenhouses for Snow Load Importance Factors

Category		Nature of Occupancy and Location of Greenhouse	Factor I_s
ASCE 7	IBC		
II	I	All commercial greenhouses that are not in ASCE 7 Category I (IBC Category IV)	1.0
I	IV	Production greenhouses that are occupied for growing plants on production or research basis, without public access	0.8

Note:

ASCE 7 Category III (IBC Category II) greenhouses where more than 300 people congregate in one area, greenhouses with capacity greater than 250 in schools, and greenhouses with capacity greater than 500 in colleges shall have a snow load importance factor of 1.1.

2.5.4.3 Sloped-Roof Snow Loads: (ASCE 7 Section 7.4) The sloped-roof snow load, p_s , shall be obtained by multiplying the flat-roof snow load, p_f , by the roof slope factor, C_s , as given in Equation 7-2.

Warm-Roof ($C_t = \text{or} < 1.0$) Slope Factor, C_s : For all greenhouses, except unheated and intermittently heated greenhouses kept just above freezing with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials), the roof slope factor shall be determined by using the following formula, as depicted in ASCE 7, Fig. 7-2a:

$$C_s = 1 - [(\theta - 5)/65] \quad (\text{when } \theta > 5^\circ)$$

where θ is the angle of slope from the horizontal in degrees.

Warm-roof slope factors for common roof slopes are given in the following Table:

Table 2.3 - Common Warm-roof Slope Factors

ROOF SLOPE	C_s
3/12	0.85
4/12	0.80
6/12	0.65
8/12	0.55
12/12	0.40
Gutter Connected	1.00

Greenhouses Kept Just Above Freezing ($C_t = 1.1$) Roof Slope Factor, C_s : For all intermittently heated greenhouses kept just above freezing with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials) the roof slope factor shall be determined from the average of the values obtained for warm-roof slope factors and cold-roof slope factors. For common roof slopes these values are given in the following Table:

Table 2.4 - Common Roof Slope Factors C_s for Just Above Freezing Greenhouse

ROOF SLOPE	C_s
3/12	0.95
4/12	0.90
6/12	0.80
8/12	0.60
12/12	0.45

Unheated Greenhouse ($C_t = 1.2$) Roof Slope Factor, C_s : For all unheated greenhouses with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials), the roof slope factor shall be determined by using the following formula, as depicted in ASCE 7, Fig. 7-2b:

$$C_s = 1 - [(\theta - 15)/55]$$

where θ is the angle of slope from the horizontal in degrees.

Unheated greenhouse roof slope factors for common roof slopes are given in the following Table:

Table 2.5 - Common Unheated Roof Slope Factors

ROOF SLOPE	C_s
3/12	1.00
4/12	0.95
6/12	0.75
8/12	0.65
12/12	0.45
Gutter Connected	1.00

Curved Roof Slope Factor, C_s : (ASCE 7, Section 7.4.3) Portions of arched greenhouse roofs having a slope exceeding 70 degrees shall be considered free of snow load (i.e., $C_s = 0$). The point at which the slope exceeds 70 degrees shall be considered the “eave” for such roofs. For arched roofs the roof slope factor shall be determined from the appropriate formula in Sections 2.5.4.3, by basing the angle of slope on the slope line from the “eave” to the crown.

Multiple Roofs Slope Factor, C_s , (Gutter-Connected): (ASCE 7, Section 7.4.4) Gutter-connected (multiple) gable, sawtooth and barrel vault greenhouse roofs shall have a $C_s = 1$, with no reduction in snow load because of slope (i.e., $p_s = p_f$). *Greenhouse design should consider future additions when the gutter is on an exterior wall or on a single building to allow for future additions.*

Ice Dams and Icicles Along Eaves: (ASCE 7, Section 7.4.5) Two types of warm roofs that drain water over their eaves shall be capable of sustaining a uniformly distributed load of $2p_f$ on all overhanging portions. These roof types include the unventilated roof with an R-value less than $30 \text{ ft}^2 \cdot \text{h} \cdot ^\circ\text{F}/\text{BTU}$, and the ventilated roof with an R-value less than $20 \text{ ft}^2 \cdot \text{h} \cdot ^\circ\text{F}/\text{BTU}$. No other loads except dead loads shall be present on the roof when this uniformly distributed load is applied.

2.5.4.4 Partial Loading: (ASCE 7, Section 7.5) Roofs with continuous beam systems need to be designed for the partial loading of selected spans with the balanced snow load, while the remaining spans are loaded with half the balanced snow load.

2.5.4.5 Unbalanced Snow Loads: (ASCE 7, Section 7.6) The combination of snow and wind from all directions contributes to unbalanced snow load conditions. The amount of the unbalanced snow load is often dependent upon the width of the building, as well as the slope of the roof. The gable roof drift parameter \mathcal{D} , based on the relative shape of the building, and the snow density g , derived from the ground snow load, are used to determine the slope of the roof that limits the amount of unbalanced snow loads for the varying roof shapes.

Balanced and unbalanced loads are to be analyzed separately.

It is important to refer to the Code- referenced ASCE 7, for proper definition and application of unbalanced snow loads.

2.5.4.5.1 Unbalanced Snow Loads for Hip and Gable Roofs: (ASCE 7, Section 7.6.1 & Figure 7-5)

For greenhouse roofs with an eave to ridge distance, W , of 20 feet or less, the structure shall be designed to resist an unbalanced uniform snow load on the leeward side. Refer to ASCE 7 for the value of the unbalanced uniform snow load to be applied. Refer also for roofs with W greater than 20', and for applicable exemptions.

Balanced and unbalanced loading diagrams are presented in Figure 7-5, ASCE.

2.5.4.5.2 Unbalanced Snow Loads for Curved Roofs: (ASCE 7, Section 7.6.2 & Figure 7-3)
Portions of curved roofs having a slope between 10° and 70° must be designed for unbalanced snow loads.

2.5.4.5.3 Unbalanced Snow Loads for Multiple Roofs (Gutter-Connected): (ASCE 7, Section 7.6.3 & Figure 7-6) Unbalanced snow loads shall be applied to folded plate, sawtooth, and barrel vaulted multiple roofs with a slope exceeding 3/8 in/ft.

2.5.4.5.4 Unbalanced Snow Loads for Dome roofs: (ASCE 7, Section 7.6.4)

2.5.4.6 Drifts on Lower Roofs (Aerodynamic Shade): (ASCE 7, Section 7.7) Greenhouse roofs shall be designed to sustain localized loads from snow drifts that form in the wind shadow of higher portions of the same structure and adjacent structures and terrain features.

Lower Roof of a Greenhouse: (ASCE 7, Section 7.7.1) Drift loads shall be superimposed on the balanced snow load. As the difference in adjacent building heights approaches zero, drift loads are not required to be applied. Refer to ASCE 7 for surcharge loads from leeward drifts, formed by snow coming from a higher upwind roof, and windward drifts, formed next to a taller downwind building.

Note that the clear height difference between the upper roof height and the top of the balanced snow load on the lower roof, h_c , as shown in Figure 7-8, ASCE, is determined based on the assumption that the upper roof is blown clear of snow in the vicinity of the drift. This is a reasonable assumption when the upper roof is nearly flat. However, sloped roofs often accumulate snow at eaves. For such roofs, it is appropriate to assume that snow at the upper roof edge effectively increases the height difference between adjacent roofs, and using half the depth of the unbalanced snow load in the calculation of h_c produces more realistic estimates of drift loads.

Adjacent Structures and Terrain Features: (ASCE 7, Section 7.7.2) The effect of higher structures or terrain features within 20 feet of a lower roof shall be considered in the design of that lower-roofed building.

2.5.4.7 Roof Projections: (ASCE 7, Section 7.8) Gives a method that shall be used to calculate drift loads on all sides of roof projections and at parapet walls. If the side of a roof projection is less than 15 ft. long, a drift load is not required to be applied to that side.

2.5.4.8 Sliding Snow: The extra load caused by snow sliding off a sloped roof of a greenhouse or other structure onto a lower greenhouse roof shall be superimposed on the balanced snow load. It shall be determined assuming that all the snow that accumulates on the upper roof under the balanced loading condition (p_s times the roof area) slides onto the lower roof. Even if the upper roof is a greenhouse roof that is an unobstructed slippery surface (and as such, is subject to lower sloped-roof snow loads as specified in 2.5.4.3), it shall be considered as not being slippery for purposes of calculating the extra sliding snow load.

The final resting-place of snow that slides off a higher roof onto a lower roof will depend on the size, position and orientation of each roof. Distribution of the sliding snow might vary from a uniform load 5 feet wide if a significant vertical offset exists between the two roofs, to a 20-foot wide uniform load where a low-slope upper roof slides its load onto a roof that is only a few feet lower or when snow drifts on the lower roof create a sloped surface that promotes lateral movement of the sliding snow.

2.5.4.9 Rain-on-Snow Surcharge Load: Rain-on-snow surcharge loads need not be considered on greenhouse roofs when they have slopes that exceed 1/2 inch per foot. However, all gutters in gutter-connected greenhouses shall be provided with adequate slope and drains to allow for run off of rain and snow melting and to prevent ponding.

2.5.4.10 Ponding Instability: Roofs shall be designed to preclude ponding instability. For roofs with a slope less than 1/4 in./ ft., roof deflections caused by full snow loads shall be investigated for ponding instability from rain-on-snow or from snow meltwater.

2.5.4.11 Existing Roofs: Existing roofs shall be evaluated for increased snow loads caused by additions, alterations, and new structures located nearby, and strengthened as necessary.

2.6 Wind

2.6.1 General

Provisions for the determination of wind loads and other wind design criteria on greenhouse structures are contained in the IBC, which in turn references ASCE 7. Whether wind loads are derived from the IBC simplified method, or from the ASCE 7 simplified or analytical methods as referenced in the IBC, the choice is up to the designer and will undoubtedly depend upon the physical characteristics of the structure and the site. The provisions found in either source apply to the calculation of wind loading on the main windforce-resisting system and the components and cladding (including glazing) of the structure.

2.6.1.1 Simplified Provisions

A simplified procedure is available in the IBC, Sec 1609.6. The determination and application of wind pressures in the design of greenhouses that are simple diaphragm buildings (see definition in the IBC) with a single gabled roof may use the procedures specified in Section 1609.6 of the *International Building Code 2000*.

There is also a simplified procedure to determine wind loads found in ASCE 7. The ASCE 7 simplified procedure has slightly different criteria for the building than the simplified procedure

in the IBC. Either may be used, provided that the building meets the conditions required for using that particular design procedure in the determination of wind loads.

Neither simplified procedure is applicable to buildings that are subject to topographic effects.

2.6.2 Definitions

Windward -toward the wind; toward the point from which the wind blows

Leeward -the side or point to which the wind blows

Simple Diaphragm Building – there may be minor discrepancies in the definition of a simple diaphragm building between the IBC and the ASCE, so it is best to refer to each specific code or standard in question. While traditional greenhouse coverings are not considered diaphragm materials, a horizontal truss system at the roof level will transfer lateral loads to vertical lateral-force-resisting systems and be considered a diaphragm.

2.6.3 Design Procedure

Design wind loads for greenhouses shall consider:

- The basic wind speed, V
- The velocity pressure q_z , where z is the height, which is calculated taking into consideration the exposure category, the surrounding terrain, the wind directionality, and the occupancy of the structure
- The design wind pressure p , which is calculated taking into consideration the direction of the wind, the exposure category, the height of the building or element, and the openness of the structure.

2.6.4 Calculation of Wind Loads

2.6.4.1 General: The design wind loads, pressures and forces are determined by the appropriate equations given in ASCE 7, Section 6.5.12 or 6.5.13; or in the case of the simplified procedure, found in Figures 6-3 and 6-4 of ASCE 7.

Gust effect factors and pressure coefficients are found in figures and tables in ASCE 7.

2.6.4.2 Basic Wind Speed: The basic wind speed, V , in miles per hour, for the determination of the wind loads shall be found in a figure in the referenced code or standard being used.

2.6.4.3 Importance Factor: Greenhouses shall be assigned a wind load importance factor, I_w , in accordance with the following Table:

Table 2.6 - Classification of Greenhouses for Wind Load Importance Factors

Category		Nature of Occupancy and Location of Greenhouse	Wind Factor I_w
ASCE 7	IBC		
II	I	All commercial greenhouses that are not in ASCE 7 Category I (IBC Category IV)	1.00
I	IV	Production greenhouses in non-hurricane prone regions and in hurricane prone regions with $V = 80-100$ mph and Alaska	0.87
I	IV	Production greenhouses in hurricane prone regions with $V > 100$ mph	0.77

Notes:

ASCE 7 Category III (IBC Category II) greenhouses where more than 300 people congregate in one area, greenhouses in schools with capacity greater than 250, and greenhouses in colleges with capacity greater than 500 shall have a wind load importance factor of 1.15.

2.6.4.4 Wind Speed-up Over Hills and Escarpments, K_{zt} : Wind speed-up over isolated hills and escarpments that constitute abrupt changes in the general topography shall be considered for buildings and other structures sited on the upper half of hills and ridges or near the edges of escarpments. The effect of wind speed-up shall not be required to be considered when hill height to distance upwind of crest of hill ratio $H/L_h < 0.2$, or when height of hill $H < 15'$ for Exposure D, or $H < 30'$ for Exposure C, or $H < 60'$ for all other exposures. Factor K_{zt} shall not be less than 1.0. Refer to Sec. 6.5.7 of ASCE 7 for further information.

2.6.4.5 Wind Directionality Factor: A wind directionality factor, K_d , shall be used in the analytical method of determining the wind velocity pressure, q_z , per Sec. 6.5.10 and 6.5.4.4 of ASCE 7. Care should be taken in applying the wind directionality factor, which is a number less than 1.0. By ASCE 7 definition, the factor is to be used with ASCE load combinations, and is contrary to use of the IBC load combinations.

2.6.4.6 Exposure Categories: For each wind direction considered, an exposure category that adequately reflects the characteristics of ground surface irregularities shall be determined for the site at which the greenhouse is to be constructed. For a site located in the transition zone between categories, the category resulting in the largest wind forces shall apply. Account shall be taken of variations in ground surface roughness that arise from natural topography and vegetation as well as from constructed features. For any given wind direction, the exposure in which a specific greenhouse is sited shall be assessed as being one of the exposure categories A, B, C, or D. Exposure categories are defined in both the IBC and ASCE 7, with minor differences between the two documents found in Exposures B and C. Reference the photos in the Commentary of ASCE 7.

2.6.4.7 Enclosure Classifications: All buildings are classified as enclosed, partially enclosed, or open. Whether the IBC or ASCE 7 is used to determine wind loads, the enclosure classifications are essentially identical. In wind-borne debris regions, special consideration is given to glazing with respect to the determination of openness.

ASCE 7 continues beyond the basic definitions to provide for clarification of buildings that fall under multiple classifications, by stating if a greenhouse by definition complies with both the “open” and “partially enclosed” definitions, it shall be classified as an “open” building. A greenhouse that does not comply with either the “open” or “partially enclosed” definitions shall be classified as an “enclosed” building.

2.6.4.8 Velocity Pressure, q_z : When using the analytical method in calculating the wind loads, the velocity pressure at height z is calculated by factoring the given basic wind speed with the velocity pressure exposure coefficient K_z , the wind speed-up factor K_{zt} , the wind directionality factor, K_d , and the importance factor I . Refer to Sec. 6.5.10 of ASCE 7.

2.6.4.9 Internal & External Pressure Coefficients and Gust Effect Factors, G_{epi} : Internal and external pressure coefficients, and gust effect factors are needed when using the analytical method of determining wind pressures. The factors are found in Sec. 6.5.11 of ASCE-7, based on physical characteristics of the structure and the site.

2.6.4.10 Design Loads and Wind Pressures: No matter which method is used in determining wind loads on a structure, the goal is to determine the worst case loading on the main wind force-resisting system and on the components and cladding.

Using the IBC simplified method of Sec. 1609.6.2, design wind pressures are given in Tables 1609.6.2.1 and are multiplied by the appropriate factors for height, exposure, and importance.

When using the simplified method of Sec. 6.4.2 in ASCE 7, design wind pressures are found in Tables 6-2 and 6-3, and are adjusted by importance, exposure or area reduction factors.

When using the analytical method of Sec. 6.5.12 in ASCE 7, design wind pressures are calculated by factoring the wind velocity pressure with internal and external pressure coefficients and gust effect factors. Sec. 6.5.13 in ASCE 7 gives the equation that is used in determining the design wind force for open buildings.

2.6.5 Wind and Seismic Detailing

The IBC requires that lateral force-resisting systems shall meet seismic detailing requirements and limitations prescribed in the code, even when wind code prescribed load effects are greater than seismic load effects, per Sec. 1609.1.5.

Seismic requirements in the IBC (Sections 1616.4 & 1620.1) state that all parts of the structure shall be interconnected. These connections are designed to resist the seismic force, F_p , induced by the parts being connected. Any smaller portion of the structure shall be tied to the remainder of the structure with a connection that shall be capable of transmitting the greater of 0.133 times the design, 5% damped, spectral response acceleration for short periods (S_{ps}) times the weight of the smaller portion, or 5% of the weight of the smaller portion to a larger portion of the structure. Each beam, girder, or truss member shall be provided with a positive connection to its support for resisting horizontal forces acting on the member. This support connection shall have sufficient strength to resist 5% of the dead and live load vertical reaction applied horizontally. Similar seismic detailing requirements are found in ASCE 7, Section 9.5.2.6.

2.7 Seismic Loads

2.7.1 Seismic Design -Background

Seismic design no longer uses the concept of seismic zones. Instead it uses maps, soil type and occupancy. The seismic maps in the building code and ASCE 7 are based on recent work by the US Geological Service. Some areas of the country have had their seismicity reduced. A number of areas are now in seismic zones that never were considered as areas having seismic potential. Seismic design requires determination of the Seismic Design Category (SDC). The SDC is a classification assigned to a structure based on its occupancy (Seismic Use Group) and the level of **expected soil modified seismic ground motion**. The SDC is determined by:

- the anticipated earthquake ground accelerations at the site,
- the type of soil at the specific site and
- the Seismic Use Group (SUG)

Because earthquake design seldom governs for greenhouses, designers may find that the use of default values may reduce the amount of calculations. All greenhouse structures would be Seismic Use Group I. The default soil type, Site Class D, simplifies the determination of the SDC. Designers will have to determine the site ground shaking (S_s and S_1) by use of the applicable seismic map. These seismic maps are contained in the building code and ASCE 7.

Using S_s and S_1 and the Site Class (soil type), coefficients S_{DS} and S_{D1} are computed. Then based on these computed values and the Seismic Use Group, the Seismic Design Category can be determined from the tables in the code or ASCE 7. The SDC directs users to specific code requirements. SDC A has minimum requirements, whereas an SDC E structure would have numerous analysis and detailing requirements.

Exceptions in the seismic design requirements (IBC 1614.1, Exception 3) include exemptions for agricultural storage buildings intended only for incidental human occupancy, areas with low S_s and S_1 values and for computed S_{DS} and S_{D1} with low values. Most production greenhouses should qualify for the agricultural exemption. However individual state and local regulations may still require design of all agricultural structures.

Once the seismic design category is determined, an R-value (a measure of the ductility of the structure) is determined from the building code (IBC Table 1617.6 or ASCE 7 Table 9.5.2.2). Greenhouse structures appear to qualify as ordinary steel concentrically braced frames, which have an R-value equal to 5. If a greenhouse is mounted on the roof of another structure, the R-value for the greenhouse is independent of that underlying structure. The connection reactions for the greenhouse shall be applied to the underlying structure's roof, just as roof-mounted equipment would be, and the supporting structure's roof shall be designed for those loads, considering all applicable load combinations.

Users should note that seismic design approaches are changing and the terms described herein may change in future codes.

Designers will have to determine whether such earthquake design loads, and the installed equipment, are critical compared to wind loads. For a greenhouse, this will depend on the

location and mass of the structure and its equipment compared to the exposed areas that the building presents.

Minimum seismic detailing requirements are given in both the IBC (Sections 1616.4 & 1620.1) and in ASCE 7 (Sec. 9.5.2.6). See Section 2.6.5 of this manual for further information.

2.8 Other Loads

2.8.1 Flood and hydrostatic

2.7.1.1 Soil and hydrostatic pressure and flood loads - *Local regulations will identify flood design zones. Whether such criteria are critical for a greenhouse will depend on FEMA and local requirements.*

2.8.2 Other Loads

Other design factors the engineer should consider in individual structures include:

- Thermal expansion and the need for joints
- Rainwater